Study on Speed-Flow Relationship Model of Urban Roadways Traffic Flow in China

YAO Chen[1], Li Chengbing[2], GAO Chao[3], HU Xinghua[4]

[1]College of Traffic and Transportation, Ludong University, Yantai, 264000, China
[2]School of Transportation, Inner Mongolia University, Hohhot, Inner Mongolia,010070, China
[3]Department of Traffic Engineering, Shandong Jiaotong University, Jinan 250023, China
[4]School of Traffic and Transportation, Beijing Jiaotong University , Beijing , 100044, China

Corresponding author is Li Chengbing

Abstract
This paper mainly studies on the speed-flow relationships of the major and minor urban roadways in China, based on the characteristic of interrupted traffic flow on the roadways. Greenshields speed-flow model is used and calibrated by using the surveying data. Due to the fact that Greenshields model can't fit the collected data very well for the congested situation, G-LN speed-flow model is then proposed by using piecewise modeling method. Greenshields model and G-LN model are compared by criterion R^2. The result is that G-LN model is better model to describe the relationship. In the end, the values of speed are calculated and the values of capacity are obtained by section iteration method. It can be seen from the calculation results that the minimum volume is between 8km/h and 10km/h, which is different from traditional concept. When volume reaches to 60% of the capacity, the traffic flow will change from uncongested state to congested state.
Keywords: TRAFFIC FLOW THEORY, SPEED-FLOW RELATIONSHIPS, MAJOR ROADWAY

1. Introduction

Research on speed-flow relationship has been an important subject in traffic flow theory. Most of the studies usually focus on expressways and highways[1][2][3], which have traffic stream characteristics for uninterrupted flow but lack of the study of the major and minor urban roadways, which show interrupted flow characteristics. Since 1930s, the study of traffic flow theory went through from free flow stage to unfree flow stage. Between 30's and 40's, the study of traffic flow theory focused on free flow theory, which showing characteristic of low density of traffic flow and long distance between vehicles. During this time, people mainly applied probability theory and mathematical statistics theory to this study.

Lighhill and Whitham applied first order continuous medium model to prove the existence of traffic shock wave. But they forgot the influence of acceleration and inertia, so it didn't reflect the dynamic characteristics of traffic flow under the nonequilibrium condition. In practice, the traffic engineering researchers found that the flow speed is monotonic decrease as the flow density increasing, which is different from the normal fluid. At the same time, there is no one existed model which can describe the relationships between speed and density.

Papageo built a traffic flow model which add a variable of entrance and exit ramp flow. It is useful to simulate the traffic flow on the high-speed way. But the performance of the model is instability under the high flow density.

Altogether, the existed flaws of traffic flow hydrodynamic model are as flow:

As the increasing of traffic flow density, the speed of flow is monotone dropping which is definitely different from the normal fluid. As the result, the classical fluid mechanics conservation equation can not explain this phenomenon.

Because the existed traffic flow models is not concerned the driver behavior, it is not instable to simulate the dynamic on-line traffic flow.

The traffic flow hydrodynamic model is more suitable to the denseness uniformity and stable flow. But It can't explain the traffic jam, go and stop traffic, and instability traffic flow.

In the calculation, it's difficult to solve the partial differential equation of traffic flow model, because the calculation process of traditional characteristic line method is complex. As far as the control is concerned, the model is need to be spatial dispersed for problem solving. But in practice, it is hard to choose the suitable discrete step.

This paper intends to describe the speed-flow relationship on the major and minor urban roadways in Beijing, China.

2. Traffic Data Processing

2.1. Data Colleciton

XueYuan Road and JinSong Road in Beijing are selected for data collection, which are characterized with both congested and uncongested traffic flow each day. The road sections are selected at the section more than 150 meters upward and downward the stop lines to prevent the influence caused by traffic flow near intersection and vehicle queue. The surveying data of every lane is collected by video camera method at daytime (6:00-18:00) working day in September 2006-2009, and transacted by Autoscope 2004 in 2 minutes as a statistic interval.

2.2. Characteristics of Surveying Data

The scatter diagram of speed and flow data is shown in Fig. 1. There are three characteristics of the surveying data.

There is no scatter point near saturation state, and the scatter points are divided into two parts. It is different from highway, which has continuous flow characteristics.

The scatter diagram is not symmetric between the congested part and the uncongested part. The changing trend is slow at upside part, while it is sharply at downside part.

When the value of volume trend to 0 veh/h, the value of speed does not run to 0 km/h, but run to a value between 5 km/h and 15 km/h, which is different from Greenshields relationship.

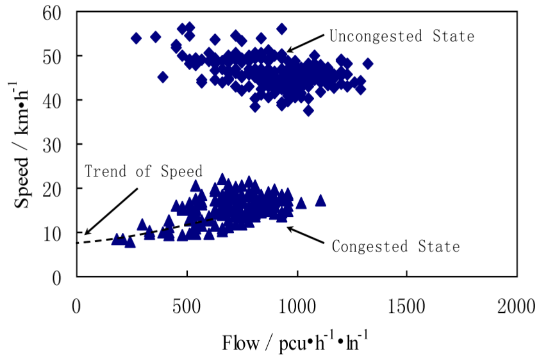

Figure 1. Speed-flow scatter diagram for traffic operation

3. Speed-Flow Models

3.1. Greenshields Model

It is obviously that volume is independent value and speed is dependent value. Because one independent value corresponds to two dependent values, these surveying data are divided into two parts to build this model.

Greenshields model (1) can be simplified to equation (2). Changing the equation from speed-flow form to flow-speed form, it can be converted to equation (3).

$$Q = K_j \left(V - V^2 / V_f \right) \quad (1)$$

$$Q = aV^2 + bV \quad (2)$$

$$V = \begin{cases} -\dfrac{b}{2a} + \sqrt{\dfrac{Q}{a} + \dfrac{b^2}{4a^2}} & V \ge V_m \\ -\dfrac{b}{2a} - \sqrt{\dfrac{Q}{a} + \dfrac{b^2}{4a^2}} & V < V_m \end{cases} \quad (3)$$

Where Q is volume (veh/h), V is speed (km/h), V_m is value of speed at maximum volume (veh/h), a and b are parameters.

The equation is programmed in statistic software, and the data is calculated and shown in Tab.1. The regression results are shown at Table.1. And the regression curve is shown in Fig.2.

Table 1. Greenshields model and parameters

Road	Road-way	Model	Range	R^2
Xue Yuan Road	I	$Q=-1.37V^2+96.27V$	0<V<70	0.902
	II	$Q=-1.41V^2+86.84V$	0<V<61	0.943
	III	$Q=-1.61V^2+82.55V$	0<V<51	0.912
Jin Song Road	I	$Q=-1.37V^2+84.2V$	0<V<61	0.954
	II	$Q=-2.05V^2+106.3V$	0<V<51	0.951

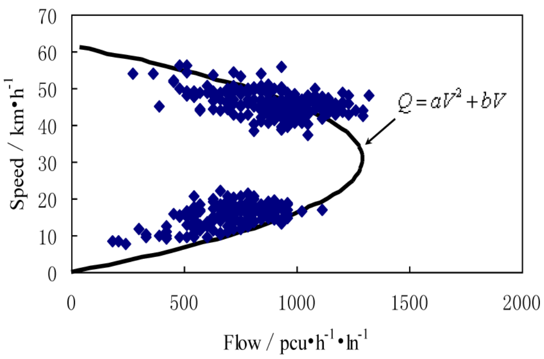

Figure 2. Regression curve of Greenshields model

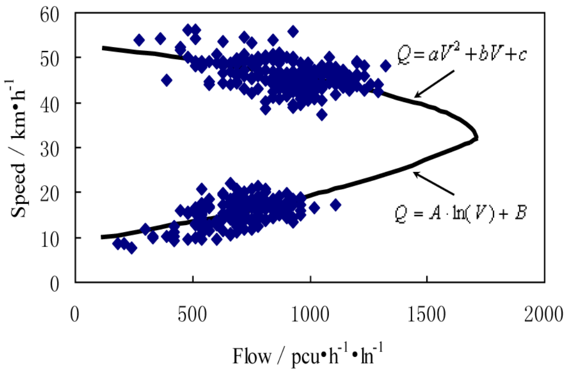

Figure 3. Regression curve of G-LN model

It can be seen from Fig.2 that the curve can't correspond to scatter diagram well at uncongested part, especially the congested part. So G-LN Model is deduced to revise Greenshields Model.

3.2. G-LN Model

The surveying data at congested state can be hypothesize as formula (4). And it can be deduced to equation (5).

$$V = a \cdot Exp(b \cdot Q) \tag{4}$$

$$Q = A \cdot \ln(V) + B \tag{5}$$

Where a, b, A, B are parameters,

$$A = \frac{1}{b}, \quad B = -\frac{\ln(a)}{b}$$

Hypothesizing equation (2) at uncongested part coheres with the surveying data and equation (5) at uncongested part coheres with the surveying data, G-LN model is obtained by piecewise modeling method[4] as equation (6). The equations are shown in Table 2, and the curve is shown in Fig.3.

$$Q = \begin{cases} aV^2 + bV + c & V \geq V_m \\ A \cdot \ln(V) + B & V < V_m \end{cases} \tag{6}$$

Table 2. G-LN model and parameters of two states

Road	Road-way	Model	Range
Xue Yuan Road	I	Q=-3.31V²+238V-1935	39<V<62
		Q=1449×LN(V)-2981	8<V<39
	II	Q=-4.5V²+295.1V-2823	40<V<53
		Q=1215×LN(V)-2705	10<V<40
	III	Q=-5.4V²+309.6V-2761	33<V<46
		Q=1185×LN(V)-2529	9<V<33
Jin Song Road	I	Q=-3.88V²+246V-2185	32<V<52
		Q=1389×LN(V)-3086	9<V<32
	II	Q=-4.65V²+260.9V-2092	29<V<46
		Q=1200×LN(V)-2492	8<V<29

4. Model Decision

Because Greenshields model is linear function and G-LN model is piecewise function, these models can't be compared with R^2. It uses mean square error to have a comparison of these two models in this paper.

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(V_{iO} - V_M)} \tag{7}$$

Where S is mean square error.

The calculating results of these two models are shown in Table.3. It can be seen from the table, the mean square error of Green-shields model is higher than that of G-LN model. So G-LN model is the better model of the two.

Table 3. Mean square error of Greenshields model and G-LN model

Road	Road-way	Green-shields Model	G-LN Model
Xue Yuan Road	I	3.135	2.968
	II	3.405	2.306
	III	2.657	2.449
Jin Song Road	I	2.377	2.369
	II	2.53	2.524

Sum up with these two comparisons, the result is easy to show: G-LN speed-flow model is the best model to describe the relationship. So this paper uses G-LN model as the optimum model.

5. Parameters of G-LN Model

The maximum speed V_{max} and minimum speed $_{min}$ are calculated, and the recommend capacities are obtained by section iteration method. The calculating results of the parameters are shown in Table.4. The comparison between 95% surveying speeds and capacities is shown in Table.5. It can be seen from the calculating results:

The maximum speed and capacity each lane is declined from the inner lane to the outer lane.

The value of minimum speed is not 0km/h, but a value between 8km/h and 10km/h. This result coheres with the actual traffic flow.

When the volume reaches to 60% of the capacity, the traffic flow disrupt from uncongested state to congested state. It can explain the phenomenon that the capacity of intersection is lower than that of road section.

Table 4. Results of data calculation

Road	Roadway	V_{max}	V_{min}	V_m	Capacity
Xue Yuan Road	I	62	8	39	2300
	II	53	10	40	1800
	III	46	9	33	1600
Jin Song Road	I	52	9	32	1700
	II	46	8	29	1600

Table 5. Comparison between 95% volume and statistic capacity

Road	Roadway	95% Volume	Capacity	V/C
XueYuan Road	I	1410	2300	61%
	II	1140	1800	63%
	III	870	1600	54%
JinSong Road	I	1140	1700	67%
	II	1110	1600	69%

6. Conclusions

It can be seen from the calculation result: the minimum speed is a value between 8km/h and 10 km/h, which is different from traditional concept.

Traffic flow will disrupt from uncongested state to congested state when volume reaches to 60% of the capacity, so traffic control and management should carry into execution before volume reach to 60% of the capacity.

The results of this study can be used to provide support and reference for capacity and level of service, study, revising the characteristics of traffic simulation, urban traffic planning, design, management and control of urban roads.

Acknowledgements

This work is supported by the Major Program of the National Science Foundation of China (Grant No. 71390332) and the National Science Foundation of China (Grant No. 60870014).

References

1. Zhang Y.P, and Pei Y.L. Research on traffic flow forecasting model based on cusp catastrophe theory. Journal of Harbin Institute of Technology (New Series), Harbin, China, 2004, Vol. 11, No. 1, p.p.1-5.
2. Shao C.Q, and Zhao L, Study of Speed-Flow Relationships Model on Urban Individual Freeway Lanes, Journal of Road Traffic & Safety, Beijing, China, June, 2006, Vol. 6, p.p. 8-9.
3. Zhuang Y and Lu S, A study of the speed-flow-density relationships on urban roads, Journal of Shenzhen University Science and Engineering, Shenzhen, China, 2005, Vol.22, NO.4, p.p. 373-376 .
4. Xu C.W, and Sun S.W, Introduction of Calculation Method, Issues in Higher Education Press, China, 225-228 p.
5. Hiroshi Sakai, Mihir Kumar Chakraborty, el. Rough Sets, Fuzzy Sets, Data Mining and Granular Computing. The 12th International Conference, Delhi, India, 2009.
6. Marzena Kryszkiewicz, James F. Peters, Henryk Rybinski. Rough Sets and Intelligent Systems Paradigms. International Conference, Warsaw, Poland, 2007.
7. GuoFang Qiu, JianMin Ma, HongZhi Yang. A mathematical model for concept granular computing systems. Science China Information Sciences, 2010, 53(7), p.p. 1397-1408.
8. T. Y. Lin, V. Kreinovich. A Special Session on Granular Computing and Interval Computations. The 19th International Conference of the North American Fuzzy Information Processing Society (NAFIPS) Atlanta, Georgia, 2000.
9. Dariusz Małyszko, Jarosław Stepaniuk. Standard and Fuzzy Rough Entropy Clustering Algorithms in Image Segmentation. The 6th International Conference, USA, 2008.
10. Davis Gary A. and Nihan Nancy L. Nonparametric Regression and Short-term Freeway Traffic Forecasting. Journal of Transportation Engineering, 1991, 117(2), p.p. 178-188.
11. Vythoulkas P.C. Alternative Approaches to Short Term Traffic Forecasting for Use in Driver Information Systems. Transportation and Traffic Theory, Elsevier Science Publishers, 1993, p.p. 485-505.